THE GEOLOGY OF THE SOUTH COAST OF NEW SOUTH WALES, WITH SPECIAL REFERENCE TO THE ORIGIN AND RELATIONSHIPS OF THE IGNEOUS ROCKS.

By Ida A. Brown, D.Sc., Linnean Macleay Fellow of the Society in Geology.

(Plate xxviii; four Text-figures.)

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1. *Introduction.*

The study of the geology of the South Coast of New South Wales reveals an interesting variety of sedimentary formations, ranging in age from lower Palaeozoic to upper Cainozoic, with which are associated igneous rocks of sub-alkaline, monzonitic and alkaline facies. Although the geological record is far from complete in this area, it is sufficiently well-preserved to show a definite relationship between the history of tectonic movement and igneous injection, and also the evolution of a series of igneous rocks, which in general gives evidence of progressive magmatic differentiation throughout the ages, commencing from Devonian or even earlier times.

The area is not a complete unit in itself; nevertheless it may be regarded as a fairly typical section across the margin of a continental mass, which has been growing by repeated deposition of sediments along its borders and their subsequent compression and elevation to form portion of the land-mass. Throughout the ages from early Palaeozoic to late Mesozoic time there has been a gradual change in the position of the axis of geosynclinal deposition and in the corresponding directions of folding and faulting of the adjacent sedimentary formations.

It is proposed therefore to give in the following pages a brief outline of the geological history of sedimentation and tectonic structure in the area under consideration and to attempt to show their possible relationships to the processes of magmatic differentiation and injection of the associated igneous rocks.

The paper is a revision of portion of a thesis accepted by the University of Sydney for the degree of Doctor of Science, and is based largely on the writer's previous studies of the igneous and sedimentary rocks of the South Coast, descriptions of which have been published in These Proceedings and in the *Journal of the Royal Society of New South Wales*.

2. Sedimentary Record.

(a). *Cambrian* (?).

The oldest bedded rocks of the region outcrop from the head of the Clyde River to the Victorian Border, a distance of 150 miles, and from the coast inland for a distance of about twenty miles. To the west they are bounded by granitic intrusions and by Upper Ordovician and newer sediments. No detailed account of this series has yet been recorded, but it is hoped that such may be given in a later paper.

These rocks consist of a series of black, banded radiolarian cherts, and metamorphosed fine-grained sediments, now converted into phyllites and schists. The cherts are turquoise-bearing, but no fossils other than radiolaria have been discovered as yet. The series is highly folded, the axes of the folds being in a meridional direction in the northern and southern portions of the area, while in the central portion, in the vicinity of Narooma, the fold axes are in the direction north-north-west and south-south-east, apparently pitching to the south-south-east. Intense minor folding and crumpling superimposed on the larger folds may be seen in a number of cliff-sections between Bateman's Bay and Bermagui.

No palaeontological evidence of the age of the series is yet known; the field-relationships of this series and fossiliferous Upper Ordovician east of Quaama indicate unconformability and suggest a pre-Upper Ordovician age for the unfossiliferous series. The extraordinary lithological characters of the series definitely distinguish it from the Upper Ordovician and newer formations occurring elsewhere in New South Wales. On the other hand these characters are remarkably similar to those of certain types of Cambrian rocks in Victoria, such as those of Heathcote (E. W. Skeats, 1908) and the phosphate-bearing rocks of the Mansfield district (A. M. Howitt, 1923). There are also resemblances to portions of the Brisbane "schist" series of Queensland, particularly the Neranleigh and Bunya Series (A. K. Denmead, 1928), and also to the pre-Silurian rocks of Cobar, Canbelego and possibly the Forbes-Parkes districts (E. C. Andrews, 1913*a*, 1913*b*, 1910).

In the absence of more definite information, the series may be regarded tentatively as of middle or upper Cambrian age.

(b). *Upper Ordovician.*

No Lower Ordovician rocks are known to occur on the South Coast, although Upper Ordovician beds outcrop two miles east of Quaama, along the eastern side of Pipeclay Creek, a tributary of the Murrah or Dry River. They occur immediately east of the granite contact, and consist of quartzites and slates from which Upper Ordovician graptolites have been obtained. These have been identified by Mr. W. S. Dun as *Diplograptus* and *Climacograptus.* Similar forms occur in weathered slate eight miles east of Cobargo, on the road to Bermagui, again not far from the granite contact.

About three-quarters of a mile north-west of Narira Trigonometrical Station, north of Cobargo, similar black slates and quartzites outcrop, and from these Mr. C. F. Laseron collected and identified *Diplograptus foliaceus, Climacograptus, Dicellograptus* (?) *gracilis, D. affinis* (W. R. Browne, 1914).

In each of these localities the beds are steeply dipping, and strike in a north-westerly direction. These are the only outcrops known to occur on the South Coast whose age can be assigned definitely to the Upper Ordovician, the main development of these formations being in a more or less meridional zone to the west of the area under consideration, extending from eastern Victoria across the border to the counties of Auckland and Wellesley, New South Wales (J. E. Carne, 1897), through the Cooma district (W. R. Browne, 1914), and northwards to the middle Shoalhaven district (W. G. Woolnough, 1909).

(c). *Upper Silurian.*

The chief development of Silurian rocks is also to the west, the only known outcrops of Silurian being in the north-western portion of the area under consideration, in the Bendithera-Wyanbene district, near the head of the Deua River.

Here fossiliferous limestones are associated with quartzites, slates and volcanic rocks. The limestones are marmorized to such an extent that the structures of the enclosed fossils are partly destroyed; the fossils identified up to the present suggest a Silurian age, although it is possible that further collecting may prove them to be Middle Devonian.

At Bendithera the main trend of the beds is in a north-westerly direction, and they are faulted against, or unconformably overlain by, sediments of probable Upper Devonian age, as described previously by the writer (1930*a*).

(d). *Upper Devonian.*

The zone of sedimentation during the Lower and Middle Devonian followed approximately that of the preceding Silurian period, and apparently did not extend as far east as the South Coast of New South Wales. Thus the Lower Devonian is represented by the Snowy River Porphyries in Victoria, and by the igneous series at the base of the Devonian in the Yass District in New South Wales; the Middle Devonian includes the limestone series of Buchan, Bindi and Limestone Creek, and the shales and limestones of Tabberabbera in Victoria (E. W. Skeats, 1929; A. W. Howitt, 1874–1877), the Yass series of limestones and shales (L. F. Harper, 1909), and the limestones and shales of Tarago and Lake Bathurst Railway Station in New South Wales.

The succeeding Upper Devonian epoch is well represented on the South Coast and has been described by the writer in a paper on the Devonian and older Palaeozoic rocks of the area between the Shoalhaven River and the Victorian border (1930*a*), and in a later paper (1931) on "The Stratigraphical and Structural Geology of the Devonian Rocks of the South Coast of New South Wales", in which the relations to other Devonian formations in south-eastern Australia are considered.

The Upper Devonian formations of the South Coast occur as a series of discontinuous outcrops extending from the coast in the vicinity of Twofold Bay in a north-westerly direction through Nerrigundah, west of Moruya to the Clyde Mountain and thence in a north-north-easterly direction towards Yalwal and the middle Shoalhaven River.

The formation always overlies the pre-Devonian sediments with a marked unconformity, and it has been divided by the writer (1931) into three stages, (i) the lower or Eden stage, consisting entirely of flows of acid volcanic rocks, 400 to 500 feet in thickness in the Eden district, and somewhat thicker (800 feet) a few miles west of Moruya; (ii) the middle or Yalwal stage, including red, freshwater shales and sandstones with interbedded volcanic flows of rhyolites and amygdaloidal basalts allied to spilites; and (iii) the Upper or Lambie stage, about 1000 feet in thickness, of shallow-water marine conglomerates, sandstones, quartzites and shales.

In the Eden district the Upper Devonian beds have suffered relatively little folding since their formation. The intensity of the folding increases somewhat towards the north, but is never great except in the vicinity of igneous intrusions, as at Araluen and Yalwal (E. C. Andrews, 1901). The axes of structural folding are parallel to the main trend of the outcrops.

(e). *Kamilaroi.*

Outcrops of Kamilaroi sediments are confined to the area north of Bateman's Bay, and have been described in detail by L. F. Harper (1915) in his Memoir on the Southern Coalfield of New South Wales. The Lower Marine Series and the underlying Carboniferous, which outcrop in the Hunter River district, are not exposed in the Southern Coalfield. Thin seams of coal belonging to the Greta Series have been identified near the head of the Clyde River and in tributaries of Wandandian Creek.

The Upper Marine Series attains a thickness of over 2,000 feet on the South Coast. The basal beds are the Ulladulla Mudstones, which have a somewhat local distribution. They are richly fossiliferous and contain evidence of contemporaneous glacial conditions in the form of ice-carried erratics and "glendonite" pseudomorphs (T. W. E. David and others, 1905; E. O. Thiele, 1903; L. F. Harper, 1915; I. A. Brown, 1925*a*). The Nowra grits contain a basal phase of Conjola conglomerate, which rests unconformably on the older Palaeozoic sediments and granite of probable late Devonian age in the neighbourhood of Conjola. The Nowra grits are overlain by crinoidal shales, which outcrop on Nowra Hill. The close of the Upper Marine Stage is represented by the extensive development of red tuffs and interbedded lava flows of the Illawarra District (L. F. Harper, 1915), and the hypabyssal intrusions of the Milton district (L. F. Harper, 1915; I. A. Brown, 1925*b*).

The overlying Upper Coal Measures outcrop along the eastern slopes of the Illawarra Tableland north of the Shoalhaven River and form the sea-cliffs between Thirroul and Stanwell Park. They dip slightly to the north and west, and underlie the Triassic sediments of the Sydney District.

(f). *Tertiary and Post-Tertiary.*

Tertiary formations occur at intervals along the coast south of the Shoalhaven River and consist chiefly of horizontally-bedded sandy sediments of lacustrine or estuarine origin, in which fragments of fossil wood frequently occur (C. Barnard, 1927). On the coast south of Corunna Lake, ferruginous grits unconformably overlie Lower Palaeozoic cherts, and from these Upper Cainozoic shells have been identified by Mr. F. A. Singleton, M.Sc., of Melbourne University. These are the only known marine Tertiary of eastern New South Wales.

Partially consolidated sandstones, grits, conglomerates and peaty beds, altogether nearly 100 feet in thickness, form old sea-cliffs behind the beaches between Bournda Island and Twofold Bay. In numerous localities there are deposits of old river gravels 40 or 50 feet above the present river level, and along the coast are old beach deposits now above the reach of high water or storm waves. The correlation and determination of the ages of these deposits is somewhat difficult and much work remains to be carried out on this problem.

Sometimes olivine-basalts are associated with the Tertiary sediments as volcanic flows, sills and dykes. Those occurring close to the coast probably were never of great thickness, but petrologically they are similar to the basalts of the Southern Tablelands which occur at Mt. Darragh, Tantawanglo, Brown Mountain and Robertson.

The contact metamorphism of Tertiary sandstones by the coastal Pliocene basalts has produced flinty quartzites that are quarried as "silica" for the manufacture of refractory bricks (I. A. Brown, 1925*c*).

3. The Igneous Rocks.

The igneous rocks of the South Coast of New South Wales and the adjacent tableland form an association which shows a progressive variation in chemical composition throughout geological time. It is considered, therefore, that a study of their occurrence may throw some light on the processes of magmatic differentiation, the relationship between the various branches of igneous rocks, subalkaline, monzonitic and alkaline, and the relation between igneous injection and tectonic structure.

Although the determination of the exact geological ages of many of the igneous occurrences is a difficult matter, it is almost certain that the chief extrusions and intrusions of subalkaline character are Devonian or older, the monzonitic rocks are probably Permian, and the relatively alkaline series of hypabyssal and volcanic rocks may be referred to the Tertiary period.

The following descriptions summarize the principal features of the field-occurrence and the petrology of the igneous rocks of the South Coast and adjacent districts.

(a). *Pre-Devonian.*

Volcanic igneous rocks occur as flows and tuffs among the Lower Palaeozoic sediments of Bateman's Bay, Moruya and Narooma. This series is tentatively regarded as equivalent to the Cambrian Heathcotian Series of Victoria. No detailed work has yet been carried out on these South Coast rocks, so that their affinities are not known with certainty.

A few dykes and thin flows of volcanic igneous rocks occur among the Upper Silurian shales and limestones of the Bendithera district, west of Moruya, but these have not been subjected to special investigation.

(b). *Devonian.*

(i). Volcanic Series.

During the Devonian period in south-eastern Australia extensive flows of acid lavas occurred over the pre-Devonian surface, along zones which were being subjected to downwarping prior to the deposition of lacustrine and marine sediments. These extravasations occurred during the Lower Devonian(?) in the Snowy River District of Victoria, and continued into the early Upper Devonian along a zone through Gippsland, Victoria, the south coast of New South Wales, and the Mudgee district. During the early Upper Devonian the rhyolites were accompanied by flows of amygdaloidal basalt or melaphyre. It will be shown later that probably the acid and basic flows were both consanguineous with the granodiorites that were intruded subsequently as batholiths along the South Coast and Southern Tablelands.

The petrological and chemical characters of the Devonian volcanic rocks of the South Coast have been described by the writer (1931), and the Victorian rocks with which they have been correlated are described by A. W. Howitt (1874–76), E. W. Skeats (1909, 1929), E. O. Teale (1920) and others.

The Upper Devonian acid lavas of the South Coast are normal potassic rhyolites, which show slight lithological variations due to differences in the conditions of consolidation. The stratigraphically lower members of the series are usually porphyritic in quartz, and have a stony groundmass, showing devitrification in thin section. In spite of the relatively high percentage of potash, the felspar crystals, when present, often consist of acid plagioclase, and it is assumed that the potash is present in the groundmass. The upper horizons of rhyolite are characterized by well-marked banding and spherulitic structures.

Table 1 illustrates the chemical composition of the South Coast rhyolites and their equivalents in the adjacent area of Victoria. Further reference will be made to them when considering the magmatic differentiation of the igneous rocks.

TABLE 1.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	75·34	75·91	78·64	78·47	72·55	62·56	74·72
Al_2O_3	11·89	11·89	9·85	10·68	11·74	16·60	13·05
Fe_2O_3	1·54	1·58	0·54	0·18	2·54	1·02	0·52
FeO	1·60	0·96	2·00	2·23	0·46	5·98	1·42
MgO	0·28	0·47	0·10	tr.	0·68	2·71	0·41
CaO	0·16	0·26	0·80	0·66	1·85	4·30	0·66
Na_2O	2·06	2·23	2·03	3·29	3·46	2·98	3·62
K_3O	3·82	5·59	5·16	4·15	4·41	2·57	4·31
H_2O+	1·18	0·58	0·40	0·2	0·41	0·68	0·61
H_2O-	0·16	0·09	0·14	0·09	0·06	0·18	0·13
CO_2	1·60	—	—	—	1·80	—	0·08
TiO_2	0·31	0·28	0·67	0·59	0·175	1·10	0·16
P_2O_5	—	—	tr.	tr.	0·14	0·17	0·38
MnO	tr.	tr.	—	—	—	tr.	—
Total	100·04	99·84	100·33	100·54	100·27	100·85	100·07

I. Rhyolite, Quarry, east of "Edrom", East Boyd, Twofold Bay. Anal. I. A. Brown, PROC. LINN. SOC. N.S.W., lvi, 1931, p. 476.

II. Rhyolite, Deua River, road to Araluen, 11 miles from Moruya. Anal. I. A. Brown, PROC. LINN. SOC. N.S.W., lvi, 1931, p. 476.

III. Banded Rhyolite, southern plateau of Wellington, Victoria. Anal. E. O. Thiele, *Proc. Roy. Soc. Vict.*, xxi, 1908, p. 266.

IV. Quartz-porphyry, southern shore of Lake Karng, Wellington, Victoria. Anal. G. Ampt, *Proc. Roy. Soc. Vict.*, xxi, 1908, p. 266.

V. Quartz-porphyrite, No. 100, Mt. Tara Ranges, Snowy River Porphyry Series. Anal. E. O. Teale, *Proc. Roy. Soc. Vict.*, xxxii, 1920, p. 125.

VI. Dacite, Willimigongong Creek, near "Cheniston", Upper Macedon, Vict. Anal. Lewis and Hall, *Bull. Geol. Surv. Vict.*, No. 24, 1912, p. 17.

VII. Rhyolite, Blue Hills, Taggerty, Vict. Anal. E. S. Hills, *Proc. Roy. Soc. Vict.*, xli, 1929, p. 189.

The associated basalts usually have an altered appearance and for this reason are commonly called "melaphyres" in Victoria. The writer has shown (1931, p. 478) that they have some affinities to the spilites and that the felspar is usually an acid plagioclase. Although many specimens contain unaltered augite, the rocks contain an abundance of alteration products which may be regarded as deuteric. These include calcite, epidote, chlorite and zeolites, which occur in the groundmass and in the amygdules, and the rock may be traversed by veins of fibrous asbestos and quartz. The following analyses are typical of the basic flows in the Devonian rocks of south-eastern Australia.

TABLE 2.

	I.	II.	III.
SiO_2	46·28	49·87	49·35
Al_2O_3	16·02	15·91	17·61
Fe_2O_3..	2·43	3·55	1·50
FeO	7·27	10·09	9·72
MgO	6·84	4·84	3·17
CaO	8·86	8·27	7·71
Na_2O	2·83	2·17	3·10
K_2O	0·25	1·10	1·56
H_2O+	3·65	2·44	2·56
H_2O-	0·30	0·19	0·65
CO_2	2·58	0·22	—
TiO_2	1·94	1·89	2·83
P_2O_5	0·34	—	tr.
MnO	0·11	pr.	0·07
Other Const. ..			0·34
Total	99·70	100·54	100·17

I. Amygdaloidal Basalt, east of Nethercote, Eden District, N.S.W. Anal. I. A. Brown, PROC. LINN. SOC. N.S.W., lvi, 1931, p. 479.

II. Compact Basalt, Por. 68, Par. Eden, N.S.W. Anal. I. A. Brown, PROC. LINN. SOC. N.S.W., lvi, 1931, p. 479.

III. Melaphyre, Moroka Snow Plain, Victoria. Anal. G. Ampt, *Proc. Roy. Soc. Vict.*, xxxii, 1920, p. 98.

(ii). Plutonic Series.

After the deposition of the Upper Devonian Series of sediments, extensive batholithic intrusions took place in central and south-eastern New South Wales, brief accounts of which have been given by W. R. Browne (1929) and E. W. Skeats (1930). So far no detailed petrological investigations of the large batholiths have been recorded.

Within the region under consideration there occurs a large granodioritic batholith, some 25 miles in width and at least 100 miles in length, which extends from eastern Victoria in a northerly direction through Towamba, Wyndham, Bemboka and Bega to beyond Cobargo. It does not outcrop on the coast, but extends from a few miles inland near Bega in a westerly direction towards Bombala and Nimmitabel on the Monaro Tableland. For convenience this intrusion may be called the Bega batholith, after the largest town on its outcrop.

Smaller granodioritic intrusions occur at Moruya, Coondella, Merricumbene and Nelligen; the Braidwood-Araluen intrusion is possibly connected with the Bega batholith by way of the Monaro tableland.

The Bega Batholith.

The boundaries of the Bega Batholith are indicated on the accompanying sketch map (Plate xxviii).

The intrusion is composite and several distinct but probably comagmatic rock-types may be distinguished: it is therefore possible that the injection of the batholith may not have taken place in a single act, or even during a single orogenic epoch, but little evidence is available on this problem, as contact with the sedimentary rocks is usually obscure. The intrusion as a whole cuts indiscriminately across the Lower Palaeozoic series; the granodiorite east of Quaama has intruded and metamorphosed fossiliferous Upper Ordovician and also Upper Devonian sediments. Near Wolumla, J. E. Carne (1897, p. 162) found evidence of the intrusion of the Wolumla granite into gently folded Upper Devonian sediments, and similar relations occur between granite and Upper Devonian beds at Upper Brogo and Bega.

Upper Devonian sediments overlie the granite north of Numbugga, a dairying settlement west of Bega, but the age relationships of the formations have not been examined. A granite at Bunnair Creek, Conjola, petrologically similar to one phase of the Bega batholith, is overlain by Upper Marine (Permian) sediments. Tertiary basalts occur over the eroded surface of the granodiorite on the eastern margin of the Monaro Tableland, on the slopes of the Brown Mountain, Tantawanglo Mountain and Mt. Darragh.

The age of at least portion of the intrusion is therefore between Late Devonian and Permian, and quite probably it belongs to the orogenic epoch at the close of the Devonian, known as the Kanimbla Epoch in New South Wales.

Although the batholith is essentially granodioritic in composition, more acid and more basic plutonic types are also developed, as well as numerous pegmatitic and aplitic veins and dykes, and a variety of basic dykes. Some of the more acid phases are associated with ore deposits of molybdenum, bismuth, tellurium, selenium, gold, silver and iron (E. C. Andrews, 1916, p. 157), and in this respect resemble the younger intrusives of the New England district (E. C. Andrews, 1905–09).

The most basic phases are the gabbros and diorites of Brogo and Quaama, which occur as inclusions of varying dimensions in more acid phases of the intrusion, and which show signs of contact-metamorphism as a result. The freshest specimens are diorites consisting essentially of basic plagioclase and hornblende.

The most widely distributed rock-type is one which is mineralogically comparable to the Moruya granodiorite; this type is common in the Cobargo district, and along the eastern portion of the batholith through Quaama and Bega. A more coarsely crystalline variety of the same rock forms the western exposure of the batholith along the lower slopes of the Monaro Tableland, outcrops occurring at Mt. Darragh, Tantawanglo, the Brown Mountain, and westwards towards Nimmitabel. The rock is a hornblende-biotite-granodiorite or tonalite consisting of quartz, plagioclase ($Ab_{65}An_{35}$ to $Ab_{70}An_{30}$), orthoclase, with microperthite, hornblende, biotite, sphene and minor accessory minerals.

The rock grades into a more acid phase by a decrease in the amount of hornblende and the presence of more acid plagioclase. This phase is a biotite-granite, which is usually porphyritic in felspar. The phenocrysts may be as much as two and a half inches in diameter and sometimes are so closely packed that the weathered rock resembles a conglomerate. In plan the outcrop of the porphyritic biotite-granite occurs within that of the granodiorite; it extends from near Yourie southwards through the Murrabrine Mountain to the west of Quaama and Bega. Good outcrops occur between Bega and Bemboka and surrounding Candelo, Wyndham, Towamba and Pericoe. The rock contains phenocrysts of orthoclase with microperthite, and the coarsely crystalline groundmass consists of quartz, orthoclase, anorthoclase and acid plagioclase of the composition $Ab_{75}An_{25}$, with biotite and minor accessory minerals. Some varieties of the rock contain muscovite, the rock thus grading into a two-mica granite in the vicinity of Towamba and Candelo.

Border phases of the batholith at Dr. George Mountain and near Yourie are aplitic granites containing little or no ferromagnesian minerals, and muscovite-granite occurs at the Whipstick or Jingera Mines east of Wyndham. This muscovite-granite consists of quartz, orthoclase, soda-microcline or anorthoclase, microperthite, albite and muscovite. Masses of red garnet occur spasmodically in the granite, which contains pipes carrying ores of bismuth and molybdenum. There is a similar occurrence on the western side of this batholith, to the south of Tantawanglo Mountain (E. C. Andrews, 1916, pp. 150–166, 143–146).

No investigation of the chemical composition of the batholith as a whole has yet been carried out, but Table 3 contains analyses of certain of the principal rock-types. The first three are analyses of acid granites from Whipstick, and are interesting in that they show that a large proportion of the orthoclase and anorthoclase must be of a sodic character. The Gabo Island granite (column iv) is probably comagmatic with the granites of the Bega batholith. The Brogo granite, whose analysis is quoted in column v, is a type of porphyritic biotite-granite containing scattered large phenocrysts of orthoclase. Granites from Braidwood, Nimmitabel and Kiandra are quoted for comparison as they are probably all of the same age.

TABLE 3.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
SiO_2 ..	87·66	83·54	75·02	72·49	69·44	69·38	66·58	65·94	65·72	45·15
Al_2O_3 ..	7·32	9·13	13·77	13·48	12·10	12·56	14·36	15·10	17·63	13·40
Fe_2O_3 ..	0·30	0·50	1·40	1·16	4·65	2·40	1·53	1·20	0·42	2·97
FeO ..	abs.	0·36	0·27	2·09	2·13	2·25	3·19	2·34	2·80	13·19
MgO ..	0·08	0·30	0·04	0·49	1·52	1·47	1·70	2·53	1·73	4·23
CaO ..	abs.	0·46	0·12	1·31	3·03	3·72	4·18	4·48	4·36	9·79
Na_2O ..	3·58	3·51	3·29	3·38	2·57	2·77	3·09	3·09	3·14	2·47
K_2O ..	0·20	1·14	4·78	4·06	3·00	3·75	3·37	3·73	2·12	0·49
H_2O+ ..	0·02	1·14	1·17	0·76	0·65	1·05	0·79	0·80	1·03	0·39
H_2O- ..	0·36	0·10	0·07	0·18	0·19	0·09	0·17	0·11	0·06	2·41
CO_2 ..	0·05	abs.	abs.	tr.	—	0·01	0·04	0·12	abs.	—
TiO_2 ..	abs.	tr.	0·30	0·46	0·55	0·52	0·65	0·55	0·41	5·04
ZrO_2 ..	abs.	abs.	abs.	—	—	abs.	abs.	abs.	0·19	—
P_2O_5 ..	0·02	0·05	0·03	tr.	0·32	0·12	0·10	0·21	0·19	0·12
$S(FeS_2)$ ..	0·16	abs.	abs.	—	—	abs.	—	abs.	0·13	—
MnO ..	tr.	abs.	0·02	0·13	—	0·04	0·07	0·04	0·08	0·19
BaO ..	tr.	abs.	abs.	—	—	0·10	0·04	0·13	abs.	—
Etc. ..	0·54	0·08	—	—	—	—	—	—	—	—
Total ..	100·29	100·31	100·22	99·99	100·15	100·23	99·86	100·37	100·01	99·84
Sp. Gr.	2·646	2·666	2·633	2·635	—	2·710	2·718	2·725	2·729	—

I. Granite, Whipstick, N.S.W. Anal. H. P. White, Dept. Mines, Geol. Surv. N.S.W., Min. Res. No. 24, 1916, p. 150.

II. Biotite-Granite, Whipstick, N.S.W. Anal. W. A. Greig, Dept. Mines, Geol. Surv. N.S.W., Min. Res. No. 24, 1916, p. 150.

III. Muscovite-Granite, Whipstick, N.S.W. Anal. H. P. White, Dept. Mines, Geol. Surv. N.S.W., Min. Res. No. 24, 1916, p. 150.

IV. Granite, Gabo Island. Anal. J. Watson, *Proc. Roy. Soc. Vict.*, xxvi, 1914, p. 268.

V. Granite, Porphyritic, Brogo. Anal. A. A. Pain, in Washington's Tables, 1917, p. 102.

VI. Granite, 6 miles north-east of Braidwood, N.S.W. *Ann. Rept. Mines Dept. N.S.W.*, 1909, p. 198.

VII. Biotite-Granite, Kybean Road, north of Bega Road, east of Nimmitabel. Proc. Linn. Soc. N.S.W., xxxiv, 1909, p. 314. (Also *Ann. Rept. Mines Dept. N.S.W.*, 1908, p. 184.)

VIII. Biotite-Granite, 7 miles south-east of Kiandra (not Kiama), N.S.W., *Ann. Rept. Dept. Mines N.S.W.*, 1909, p. 198.

IX. Granodiorite, 2 miles east of Moruya, N.S.W. Anal. I. A. Brown, Proc. Linn. Soc. N.S.W., liii, 1928, p. 162.

X. Gabbro, Brogo, N.S.W. Anal. A. A. Pain, in Washington's Tables, 1917, p. 662.

The only small granitic intrusion whose petrology has been studied in detail is that at Moruya (I. A. Brown, 1928), but field-observations and brief examination of hand-specimens and thin sections of the rock-types of the other intrusions indicate that the Moruya series is representative of the smaller granitic intrusions. The Moruya plutonic series, with its associated dyke-rocks, forms a complete and typical subalkaline igneous complex. The principal plutonic types are biotite-granite, granodiorite, tonalite and diorite-gabbro, whose occurrence and relationships have been described in detail by the writer (1928). Aplitic and lamprophyric dyke-rocks are closely associated with the intrusion.

The other small intrusions appear to consist essentially of types comparable to the more acid phases of the Moruya complex. This feature may be due to the fact that they have not been sufficiently eroded to expose the more basic types which, even in the case of the Moruya intrusion, form only a small part of the whole. Chemical analyses of the chief types are quoted in Table 4.

(c). *Kamilaroi.*

Rocks of a monzonitic character occur in the northern part of the area under consideration, where three main groups have been studied in detail. These comprise (i) a series of volcanic flows of latite occurring chiefly in the Illawarra District, north of the Shoalhaven River, (ii) hypabyssal intrusions of monzonite-porphyry in the Milton District, and (iii) a monzonitic igneous complex in the Mount Dromedary district.

(i). In the Illawarra District, volcanic flows of monzonitic composition are interbedded with tuffs in the Upper Marine Series of Permian age. Their occurrence has been mapped and described by J. B. Jaquet (1905) and L. F. Harper (1915), and petrological descriptions of the rocks have been given by G. W. Card (1915) together with chemical rock-analyses by officers of the Department of Mines, New South Wales. Seven distinct flows have been recognized; they all occur within 15 miles of the present coast-line "and conform to the dip of the sedimentary rocks in every case" (Harper, 1915, p. 290). Although the rocks show marked mineralogical and textural variations, the relative uniformity of the chemical composition indicates that the flows are all consanguineous. They are described by Mr. Card as latites and latitic dolerites, and are usually black rocks of basaltic appearance, containing phenocrysts of plagioclase (generally labradorite) in an aphanitic groundmass. Under the microscope the groundmass is seen to be holocrystalline, and to consist of augite, plagioclase, orthoclase and minor

TABLE 4.

	I.	II.	III.	IV.	V.
SiO_2	49·38	50·44	61·44	65·72	70·78
Al_2O_3	13·89	17·05	17·61	17·63	15·77
Fe_2O_3	1·89	2·43	1·86	0·42	0·69
FeO	6·03	5·24	3·59	2·80	2·44
MgO	15·82	10·85	3·09	1·73	0·72
CaO	10·12	9·80	5·88	4·36	2·53
Na_2O	0·54	1·51	2·03	3·14	2·88
K_2O	0·69	0·92	1·03	2·12	2·44
H_2O+	0·58	0·65	1·17	1·03	0·50
H_2O-	0·13	0·06	0·10	0·06	0·06
TiO_2	0·96	1·10	1·42	0·41	0·45
P_2O_5	0·30	0·43	0·33	0·19	0·25
MnO	0·14	0·11	0·09	0·08	0·08
Etc.	—	—	—	0·32	—
Total	100·74	100·59	99·64	100·01	99·59
Sp. Gr.	2·989	2·932	2·768	2·729	2·688

I. Gabbro, Kelly's Point, 8 miles south-east of Moruya.
II. Diorite-gabbro, Kelly's Point, 8 miles south-east of Moruya.
III. Tonalite, Kelly's Point, 8 miles south-east of Moruya.
IV. Granodiorite, 2 miles east of Moruya.
V. Biotite-granite, 3 miles north-west of Moruya.
Analyst, I. A. Brown, PROC. LINN. SOC. N.S.W., liii, 1928, p. 182.

accessory minerals, apatite and magnetite. Olivine is sometimes present. Some varieties are amygdaloidal, the vesicles containing chlorite and calcite or even zeolites. Certain phases have suffered deuteric alteration in some localities (W. R. Browne and H. P. White, 1928).

(ii). In the Milton District, monzonitic rocks occur as intrusions in horizontally-bedded Upper Marine sandstones which are stratigraphically below the tuffs of the Illawarra District.

The petrology of the Milton district has been described by G. W. Card (1905, 1915) and subsequently by the writer (1925*b*). The main intrusion outcrops over an area of about 16 square miles and has a thickness probably not exceeding 400 feet. Sill-like intrusions of similar rocks occur at Little Forest, the Pointer Mountain and Yatteyattah, which vary from 50 feet to 300 feet in thickness. The principal rock-types are monzonite, monzonite-porphyry and banatite, the latter being a fine-grained marginal phase of the intrusion. Some of the more coarsely crystalline phases have suffered deuteric alteration.

A somewhat similar intrusion occurs at Woodburn, 15 miles south of Milton, and a more coarsely-crystalline phase outcrops on the coast near Murramarang and Bawley Point, apparently as an interbedded flow in the Upper Marine sandstones. The latter includes a type of olivine-monzonite approaching an essexite (L. F. Harper, 1915, p. 310; I. A. Brown, 1925*b*, p. 464).

(iii). The igneous complex at Mt. Dromedary, 70 miles south of Milton, has been described in detail by the writer (1930*b*). It outcrops over an area of about 25 square miles, including the whole of the Mountain. The distribution of the rock-types comprising the intrusion indicates that it is in the form of a laccolith at least 3,000 feet in thickness. The original cover has been worn away entirely, and the surrounding rocks consist of highly folded older Palaeozoic sediments. A study of the occurrence of Upper Devonian sediments along the South Coast suggests, however, that the Upper Marine stage formerly extended over the area now occupied by the Dromedary Mountain (I. A. Brown, 1931). Since the Upper Devonian rest on Ordovician sediments with a very strong unconformity, it seems quite possible that the igneous injection took place along this unconformity, and that the intrusion was in the form of an inter-formational laccolith.

The intrusion is essentially monzonitic in character and includes a great variety of plutonic and hypabyssal types. The main plutonic series consists of banatite, monzonite, olivine-monzonite and pyroxenite, with a related series of nepheline-bearing rocks, ijolite, nepheline-monzonite and nepheline-shonkinite or covite, and a series of melanite-bearing pyroxenites and melteigite-jacupirangites. Associated with these are some hypabyssal monzonitic rocks which resemble some of the Milton types. These occur in the form of minor plug-like intrusions about the foothills of the Mountain, and contain fragments of the more basic monzonitic rocks and also essexite and other types not known to be exposed in the main intrusion. Similar rocks outcrop on Montague Island, seven miles east of Narooma.

Table 5 illustrates the chemical composition of the Permian monzonitic rocks; the analysis quoted in column i is representative of the latitic flows of the Illawarra, that in column ii of the monzonite-porphyry at Milton, and the remaining analyses are of the chief plutonic types in the monzonitic series at Mt. Dromedary.

(d). *Tertiary.*

Associated with the Kamilaroi and Triassic sediments of the Illawarra District are a number of alkaline rocks and rocks with alkaline affinities, which occur as dykes, sills, volcanic necks and volcanic flows.

These rocks have been described in considerable detail by L. F. Harper (1915), G. W. Card (1915), and others. The variety of comparatively rare rock-types developed in this area makes it one of great petrological interest. The rocks comprise (i) several varieties of lamprophyre, including mica-lamprophyre, hornblende-lamprophyre or camptonite and a number of monchiquites; (ii) syenite, nepheline-syenite and tinguaite; and (iii) olivine-bearing and analcite-bearing basalts and dolerites.

This series is believed to be of Tertiary age, but the exact age of particular members can rarely be determined. By analogy with igneous rocks of similar character in other parts of the State it is generally considered that the lamprophyres and alkaline syenites are of early Tertiary age, possibly Eocene, and that the basaltic rocks are somewhat younger. Some of the latter overlie sediments containing Tertiary plant-remains. T. G. Taylor and D. Mawson (1903, p. 346) were also of the opinion that the basalt flows of the Bowral district were subsequent to the syenitic intrusions, and were probably of late Tertiary, Pliocene, age.

(i). The lamprophyres occur as volcanic necks in the Good Dog Mountains and near Robertson (Wallaya), and also as dykes. The variety monchiquite, consisting of augite, magnetite and analcite, occurs as sills at Mt. Nebo (west of Wollongong) and at Rixon's Pass (west of Bulli), and as numerous dykes (G. W.

Card, 1915, p. 358). The lamprophyres are always porphyritic, the phenocrysts being pyroxene, amphibole or mica, set in a very fine-grained groundmass composed of some of the following minerals: plagioclase, orthoclase, pyroxene, hornblende, quartz, apatite, sphene and iron ores.

TABLE 5.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	52·42	53·21	43·63	48·34	51·14	59·44	64·49
Al_2O_3	18·05	17·84	7·52	11·79	16·91	19·58	17·48
Fe_2O_3	4·30	3·80	6·45	2·31	1·34	0·31	1·64
FeO	3·60	5·22	8·57	7·72	7·27	3·91	1·69
MgO	3·60	2·96	13·67	9·59	5·88	1·27	0·66
CaO	6·14	6·48	17·12	12·76	9·68	3·95	3·28
Na_2O	3·75	3·36	0·36	1·60	1·92	3·21	4·16
K_2O	4·14	3·03	0·50	3·17	3·32	6·60	4·79
H_2O+	1·47	1·27	0·46	0·68	0·54	0·88	0·52
H_2O-	1·07	0·65	0·25	0·04	0·20	0·12	0·18
TiO_2	1·16	1·01	1·24	0·88	0·92	0·54	0·46
P_2O_5	0·34	0·44	tr.	0·87	0·53	0·07	0·22
MnO	0·28	0·32	0·20	0·15	0·14	0·07	0·11
Etc.	0·28	0·29	—	—	—	0·49	0·77
Total	100·60	99·88	99·97	99·90	99·79	100·44	100·45
Sp. Gr.	2·722	2·768	3·393	3·085	3·017	2·679	2·653

I. Bumbo Flow, Bumbo Quarry. Anal. H. P. White, *Rec. Geol. Surv. N. S. Wales*, viii, 1905-1909, p. 12.

II. Latite (Banakite), Milton. Anal. A. H. Greig, *Mem. Geol. Surv. N. S. Wales*, Geology 7, 1915, p. 320.

III. Pyroxenite, Tilba Tilba Lake. Anal. I. A. Brown, PROC. LINN. SOC. N.S.W., lv, 1930, p. 664.

IV. Shonkinite, Tilba Tilba. Anal. I. A. Brown, PROC. LINN. SOC. N.S.W., lv, 1930, p. 656.

V. Olivine-Monzonite, two and a half miles south-west of Tilba Tilba. Anal. I. A. Brown, PROC. LINN. SOC. N.S.W., lv, 1930, p. 653.

VI. Monzonite, north-west of Tilba Tilba. Anal. I. A. Brown, PROC. LINN. SOC. N.S.W., lv, 1930, p. 647.

VII. Banatite, Mt. Dromedary. Anal. I. A. Brown, PROC. LINN. SOC. N.S.W., lv, 1930, p. 644.

Several of the lamprophyric and monchiquitic dykes contain large xenocrysts of brown hornblende and augite, and ultrabasic xenoliths in monchiquitic dykes are recorded by W. N. Benson (1914) and C. A. Süssmilch (1905). A lamprophyric dyke south of Moruya (I. A. Brown, 1929) contains xenoliths of ultrabasic plutonic rocks, lherzolite and pleonaste-pyroxenite, and numerous xenocrysts of red garnet, brown hornblende, augite and basic plagioclase.

Chemical analyses of twelve lamprophyres and monchiquites have been carried out in the laboratory of the Department of Mines, Sydney, and are recorded by L. F. Harper (1915, pp. 325–360). A few typical analyses are quoted in Table 6.

TABLE 6.

	I.	II.	III.	IV.	V.
SiO_2	46·50	51·02	39·35	41·72	42·52
Al_2O_3	16·48	16·98	11·60	16·87	16·82
Fe_2O_3	3·80	5·52	3·32	5·90	2·90
FeO	7·47	4·13	7·38	3·87	7·56
MgO	3·46	4·13	9·82	4·23	6·43
CaO	6·14	6·37	12·66	10·32	9·78
Na_2O	4·19	3·61	2·00	4·99	4·02
K_2O	4·54	2·98	1·77	2·73	1·31
H_2O+	3·57	1·95	3·82	3·67	5·51
H_2O-	0·21	1·01	1·28	0·45	0·47
CO_2	0·28	0·35	4·04	2·54	0·07
TiO_2	2·40	1·44	1·98	1·70	1·30
P_2O_5	1·13	0·30	0·64	0·85	1·46
MnO	0·15	0·29	0·21	0·15	0·15
BaO	0·08	0·25	0·08	0·13	0·04
Etc.	tr.	0·28	0·55	0·12	0·03
Total	100·40	100·61	100·50	100·24	100·37
Sp. Gr.	2·765	2·788	2·915	2·732	2·812

I. Mica-lamprophyre, volcanic neck (?), Robertson. Anal. H. P. White, *Mem. Geol. Surv. N.S.W.*, Geol. No. 7, 1915, p. 338.
II. Hornblende-lamprophyre, dyke, Good Dog Mts. Anal. J. C. H. Mingaye, *ibid.*, 328.
III. Monchiquite, Kiama. Anal. H. P. White, *ibid.*, p. 360.
IV. Monchiquite (Fourchite), Mt. Nebo. Anal. J. C. H. Mingaye, *ibid.*, p. 344.
V. Monchiquite, Rixon's Pass. Anal. H. P. White, *ibid.*, p. 348.

(ii). Alkaline syenites also occur as sills and volcanic necks on the Illawarra Coast and adjacent tableland. The Jamberoo sills consist of nepheline-syenite and the Dhruwalgha sill is of finer-grained tinguaite. With these may be grouped the volcanic necks of the Bowral Gib and Mt. Jellore, described by T. G. Taylor and D. Mawson (1903) and which consist essentially of alkaline syenite associated with alkaline basic and ultrabasic rocks, essexite and picrite.

Chemical analyses of the principal types are quoted in Table 7.

(iii). The basalts and dolerites occur as dykes, sills and volcanic flows. The dykes are most easily identified along the coastal rock-platforms and usually consist of fine-grained basaltic rock. The sills show greater variation in texture and composition although they are not of great thickness or extent. Basaltic flows form a capping to the Illawarra Tableland in the vicinity of Robertson, and south of the Shoalhaven River basalt occurs on the Sassafras tableland (G. W. Card, 1915, p. 286); thin flows outcrop near Milton, Moruya, Bodalla, Yellow Pinch (Wolumla) and elsewhere (I. A. Brown, 1925*c*, 1931). The columnar basalt of Mt. Darragh is portion of an extensive basalt flow or series of flows, which form the surface of the Monaro tableland and extend to Bombala and Nimmitabel.

TABLE 7.

	I.	II.	III.	IV.
SiO_2	54·50	55·82	55·86	55·16
Al_2O_3	17·81	20·19	15·25	16·67
Fe_2O_3	1·70	3·70	4·92	2·36
FeO	5·30	1·17	6·07	7·31
MgO	1·09	0·25	0·20	0·56
CaO	2·64	1·02	2·13	2·30
Na_2O	5·39	9·57	2·34	5·65
K_2O	6·08	5·60	9·28	6·97
H_2O+	3·78	1·30	0·50	0·88
H_2O-	0·54	0·15	0·70	0·85
CO_2	0·30	0·04	1·80	1·50
TiO_2	0·44	0·01	0·65	0·60
P_2O_5	0·44	0·07	0·16	0·38
MnO	0·25	0·36	0·42	0·47
BaO	abs.	tr.	tr.	tr.
Etc.	0·02	0·55	0·14	0·42
Total	100·28	99·80	100·39	100·80
Sp. Gr.	2·595	2·594	2·706	2·675

I. Nepheline-syenite, sill, Kangaroo Valley, Jamberoo. Anal. W. A. Greig, *Mem. Geol. Surv. N.S.W.*, Geology No. 7, 1915, p. 339.

II. Tinguaite, sill, Dhruwalgha. Anal. J. C. H. Mingaye, *ibid.*, p. 341.

III. Syenite (melanocratic), Bowral. Anal. T. G. Taylor and D. Mawson, *Journ. Roy. Soc. N.S.W.*, xxxvii, 1903, p. 341.

IV. Syenite (leucocratic), Bowral. Anal. T. G. Taylor and D. Mawson, *ibid.*, xxxvii, 1903, p. 341.

The basalts are generally compact, and, unlike the Kamílaroi basaltic rocks (latite), are not usually porphyritic in felspar. They consist essentially of laths of plagioclase and augite, the latter mineral occurring either as small rounded grains producing intergranular fabric, or as plates including laths of plagioclase and giving an ophitic fabric to the rock. As a rule olivine and iron ores are present and analcite frequently occurs. Nepheline is present in some cases, as in the theralitic basalt from Bombala (W. R. Browne, 1927, p. 377), but generally occurs only in the norm. Table 8 illustrates the chemical composition of these rocks.

The first four analyses (in Table 8) of New South Wales rocks are remarkably similar considering that they come from widely separated localities. They are all undersaturated in silica and show about 20 per cent. of olivine and a small amount of nepheline in their norms. Three fall into the same subrang, Auvergnose, in the American Quantitative Classification, while the Cordeaux analcite-dolerite belongs to the closely related subrang Camptonose.

It is thus evident that these basalts do not strictly belong to the "plateau basalts" in the sense used by H. S. Washington (1922, p. 797), who states: "In the typical plateau basalts . . . . no nephelite is present, although some nephelite basalts or tephrites accompany the normal basalts in a few places. . . . . Olivine is generally rare, ... Quartz is not usually present in these basalts, although many of them show an excess of silica in the norm." An average of 11 analyses made by Washington of the Deccan basalts is quoted for comparison in column vi.

TABLE 8.

	I.	II.	III.	IV.	V.	VI.
SiO_2	44·57	46·20	44·35	44·08	45·25	50·61
Al_2O_3	15·30	17·44	14·71	16·70	16·47	13·58
Fe_2O_3	3·20	1·30	3·08	2·77	2·44	3·19
FeO	7·83	9·54	8·21	8·08	8·69	9·92
MgO	10·04	7·38	10·63	9·25	7·77	5·46
CaO	10·00	9·02	10·08	9·49	8·90	9·45
Na_2O	1·94	3·69	1·64	2·01	2·68	2·60
K_2O	1·39	1·10	1·39	1·74	1·42	0·72
H_2O+	3·21	2·11	3·04	2·45	1·60	2·13
H_2O-	1·09	0·09	0·72	0·64	0·70	
CO_2	0·01	0·04	tr.	tr.	—	—
TiO_2	1·01	1·30	1·95	2·03	3·20	1·91
P_2O_5	0·41	0·56	0·59	0·50	0·43	0·39
MnO	0·29	0·17	0·15	0·16	0·38	0·16
BaO	0·05	0·03	—	—	—	—
Etc.	0·09	—	—	—	—	—
Total	100·43	99·97	100·52	99·90	99·93	100·12
Sp. Gr.	2·907	2·934				

I. Analcite-basalt (Robertson Flow), 5 miles west of Jamberoo. Anal. H. P. White, *Mem. Geol. Surv. N.S.W.*, Geol. No. 7, 1915, p. 288.

II. Ophitic analcite-dolerite (Cordeaux Flow), half a mile east of Wanyambilli. Anal. H. P. White, *ibid.*, 1915, p. 289.

III. Basalt, 12 miles north of Bombala. Anal. I. A. Brown.

IV. Basalt, half a mile south of Nimmitabel. Anal. I. A. Brown.

V. Olivine-basalt, Lago Buenos Airos, Argentina. Anal. Herdman, *Journal of Geology*, xl, 1932, p. 379.

VI. Average of 11 analyses of Deccan basalts. H. S. Washington, *Bull. Geol. Soc. Amer.*, xxxiii, 1922, p. 797.

On the other hand the basalts are very similar in all respects to the Patagonian basalt, whose analysis is quoted in column v. This rock is described by G. W. Tyrrell (1932, p. 374) as a "plateau-basalt in the restricted sense of Gregory and Reck. This type contrasts with that of flood-basalts, which, in general, are over-saturated with silica."

The alkaline affinities of many of the Tertiary basalts of Eastern Australia are recognized by Sir T. W. E. David (1932, p. 103).

4. TECTONIC HISTORY AND IGNEOUS ACTIVITY.

The distribution of outcrops and the variation in the conditions of sedimentation as revealed by the lithological and palaeontological characters of the lower and middle Palaeozoic rocks of the South Coast of New South Wales supplies a considerable amount of evidence on the history of the building of south-eastern Australia and the changes in the palaeogeography of this region during lower Palaeozoic time.

The oldest sediments, possibly of Cambrian age, indicate deposition under marine conditions; normal sedimentation was accompanied by deposition of tuff and other products of submarine igneous activity. The vast thickness and extent of this formation suggests that the landmass from which these sediments were derived was not far distant, and probably was situated to the east. This land may have been the predecessor of the "Tasmantis" of Süssmilch and David (1919).

The palaeogeography of Australia during the previous Pre-Cambrian period has been considered recently by L. A. Cotton (1930), who suggests for the Pre-Cambrian framework (1930, figure 4, p. 55) a main south-western block named Yilgarnia separated from three borderland masses, the Kimberley massif, the Carpentaria massif and the eastern massif of Tasmantis, by the Nullagine geosyncline.

This conception of the Australian framework is comparable with that envisaged by C. Schuchert (1923) for the continent of North America. Schuchert states (p. 158): "From the geographic position of the geosynclines near the margins of the continent, and the further fact that the main masses of their sediments came not from the medial area of the continent, but from more or less narrow lands facing the oceans, it is clear that North America was originally much more extensive than now. Since these facts are already true in Lower Cambrian time, it is also clear that the extent of greater North America was established in Proterozoic time." These ideas may be applied with equal truth to the continent of Australia.

The early Palaeozoic history of south-eastern Australia is chiefly that of the infilling of the southern part of the Nullagine geosyncline. Thus Cambrian (?), Upper Ordovician, and Upper Silurian sediments were deposited in the New South Wales portion of the geosyncline, the apparent absence of Lower Ordovician and Lower Silurian sediments being due either to lack of knowledge of outcrops or to the possibility that during these epochs the sea was withdrawn to the south and that no sedimentation took place in New South Wales. Upper Ordovician rocks extend eastwards to a few miles east of Quaama and Cobargo, the Upper Silurian to the upper part of the Deua River. The geosyncline during Lower and Middle Devonian time apparently was narrower than it had been formerly, but extended from eastern Victoria into New South Wales through Yass and Tarago to the Mudgee district. During the Lower and Middle Devonian epochs the present South Coast was an area of non-deposition, probably forming part of the borderland of Tasmantis.

At the end of the Middle Devonian the southern part of the Nullagine geosyncline was finally closed up and the south coastal portion of New South Wales was permanently welded on to the continental mass of Australia. As a result of this diastrophism the Middle Devonian sediments were folded in a meridional direction and possibly epeirogenic uplift accompanied the orogenic movements (I. A. Brown, 1932).

The Upper Devonian commenced with an epoch of igneous activity represented by enormous flows of acid volcanic rocks, which form the Eden stage of the series. No volcanic centres have been recognized; possibly the flows were associated with fracture and faulting preceding the formation of a marginal geosynclinal trough in which later sedimentation occurred. Gradual subsidence followed and lacustrine sediments of the middle or Yalwal stage are associated with contemporaneous flows of rhyolite and basalts allied to spilites. The upper or Lambie stage of marine sediments was deposited over a wide area of New South Wales, the deepest part being towards the east. The western portion of this sea was not geosynclinal, but was rather of the nature of a flood over the relatively stable continental massif. Thus a thin veneer of late Upper Devonian arenaceous sediments was deposited over highly folded pre-Devonian rocks, and these were not afterwards subjected to intense folding.

The intensity of the diastrophism at the close of the Middle Devonian is further emphasized by the marked differences in the lithological characters of the Middle and Upper Devonian sediments, in the deposition of thick clastic sediments in the Upper Series, and also by the marked palaeontological break between the two series. Unconformable contact has been observed only in Victoria.

After the deposition of the Upper Devonian sediments orogenic movements affected the greater part of south-eastern Australia: the Eden district became portion of the stable land block, which has suffered no later orogenic movement, and the area of instability moved northwards. This late Devonian orogeny was accompanied by the intrusion of great granodioritic batholiths, an association of fold-movement and intrusion of subalkaline magma which supports the views of A. Harker (1909) regarding the distribution and origin of igneous rocks.

The elongation of the main batholith described earlier in this paper, and also the longer axes of the smaller batholiths are parallel to the general direction of the trend lines of the Upper Devonian sedimentary rocks of the South Coast.

There are no signs of Carboniferous sedimentation in the area, and it is inferred that the area formed part of a land-mass during this time.

The development of the Kamilaroi geosyncline to the north and east resulted in heavy sedimentation. During the Upper Marine stage there were vertical adjustments of the adjacent landmass (without strong folding movements) and these were accompanied by the deposition of tuffs and flows of latite in the Illawarra district, by sill-like intrusions in the Milton district and by laccolithic intrusion in the Mt. Dromedary district. These intrusions were monzonitic in character, or rather more alkaline than those of the preceding period of igneous activity.

No important orogenic movement has taken place on the South Coast since the close of Palaeozoic time. The axis of geosynclinal sedimentation gradually moved northwards towards Sydney and post-Palaeozoic earth-movements were mainly vertical adjustments, broad warping with some faulting. These movements were accompanied by the extravasation of highly differentiated alkaline magma in the form of dykes, sills and volcanic necks. The earlier intrusions were lamprophyric and syenitic, and the later occurrences were of alkaline basalt.

The association of intrusions of more alkaline rocks with the later epeirogenic movements of the area again supports the generalization of A. Harker (1909) concerning the relation of the chemical composition of igneous intrusions to the associated type of earth-movement.

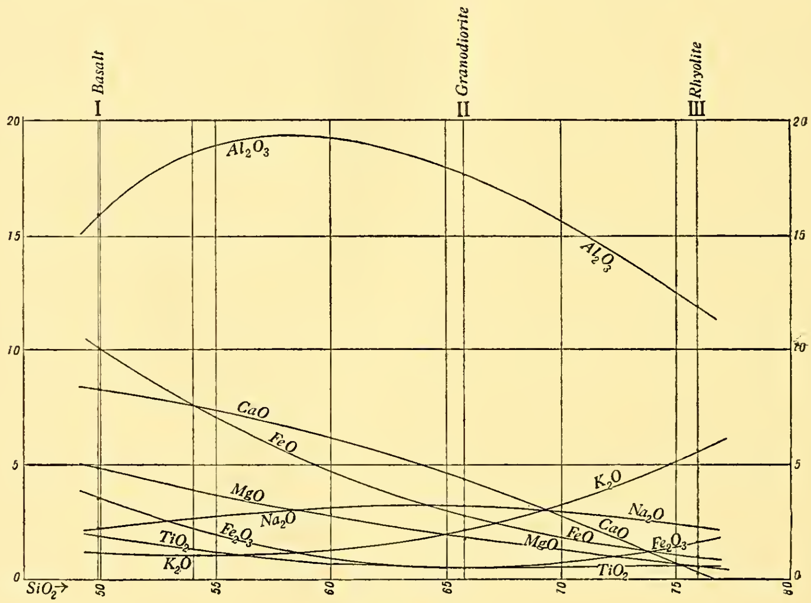
The Tertiary earth-movements affected the whole of eastern New South Wales and culminated in general elevation during the Kosciusko epoch. The east-west trend of the majority of the dykes on the South Coast suggests that the crust of the earth here was in a state of relative tension in a meridional direction. This may be an expression of relative compression in an east-west direction, for the plateau-building forces operated in a direction at right-angles to the trend of the coast-line and the coastal plateaux.

More recent tectonic history is concerned mainly with oscillatory movements about the present coast-line and the development of the present physiography. No igneous activity is known to have occurred since Tertiary time.

5. Magmatic Differentiation.

Many problems of magmatic differentiation present themselves in a study of the igneous rocks of the South Coast. These may be divided into two groups: (*a*) those of a local character, which are related to the petrogenesis of rock-series occurring in a limited area, and (*b*) those of a regional character, which are concerned with the ultimate consanguinity of rock-series of several petrographical provinces.

(*a*). The effects of local magmatic differentiation have been considered previously by the writer in the cases of the Milton (1925*b*), Moruya (1928) and Mount Dromedary (1930*b*) intrusions, but for the sake of completeness these will be summarized in the following account.



Text-figure 1.

There can be no doubt that the South Coast was portion of a petrographical province during the early and middle Palaeozoic era, and that the igneous intrusions and extrusions were typically subalkaline in character. The widespread extrusions of rhyolite and basalt during the Devonian suggest that similar magmatic and tectonic conditions obtained over a zone several hundred miles in length, following the margin of early Upper Devonian sedimentation. There is no obvious genetic relationship between the rhyolites and the basalts, but the granodiorite, which was injected as batholiths at the close of the Devonian, is possibly related to both the earlier volcanic types.

The accompanying variation-diagram, Text-figure 1 (of the type used by A. Harker, 1909) is based on three analyses, which are regarded as typical and representative of the (Devonian) rhyolites, granodiorites and basalts of the South Coast. These are of (i) the basalt from Nethercote, near Eden (p. 340), (ii) the granodiorite from Moruya (p. 344) and (iii) the rhyolite from the Lower Deua River (p. 339) whose analyses have been quoted in an earlier part of the paper. The points representing the various oxides are joined by simple curves, the form of the alumina curve towards the basic end being determined by comparison with the sum of the other oxides.

The resultant diagram is that of a typical subalkaline series, with the characteristic features as defined by Harker (1909, p. 130): "The flat convex shape of the alumina curve, the declining concave curves of magnesia and ferric oxide, the lime with its maximum near the basic end, the soda with its maximum near the acid end, and the steady rise in the potash-line".

It is therefore considered by the writer that the Devonian rhyolites and basalts are genetically related to the granodiorites, and that they represent complementary differentiates of the granodioritic magma. The cause of the differentiation is not apparent. Evidently differentiated magma underlay the region during early and middle Palaeozoic time; the early Devonian earth-movements were probably of the nature of trough faulting and broad warping, which permitted the extravasation of the acid and basic differentiates as volcanic flows. An interesting feature is that, as previously shown (1931), the basalts are allied to spilites and are associated with movements of subsidence, a feature which is characteristic of spilites in other parts of the world. The main granodioritic magma was not injected until after the close of the Upper Devonian, during a period of crustal folding.

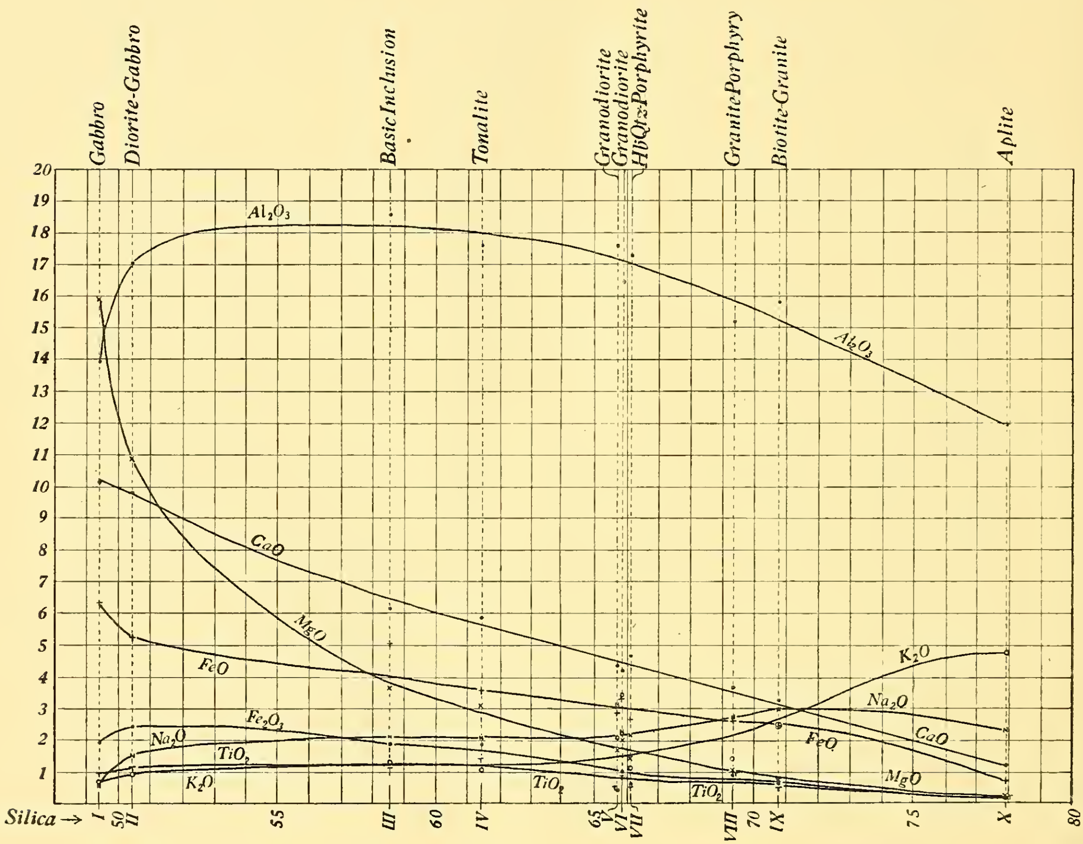
In a recent paper to the Geological Society of London (1932), Dr. A. Brammall has indicated that possibly the Dartmoor granites and the spilites of Devon and Cornwall are genetically related. In the discussion following the reading of the paper, Sir John Flett pointed out that in Ayrshire . . . "the spilitic eruptions had been followed, as in Devon, by a period of intense folding. After a short interval the folded rocks were invaded by a new magma, represented by the Galloway granites."

The similar magmatic and tectonic conditions during Devonian time in Britain and on the South Coast of New South Wales, certainly indicate some causal connection between the processes of magmatic differentiation and earth-movement.

The granodioritic magma injected after the deposition of Upper Devonian sediments on the South Coast took the form of a large batholith, extending from Victoria into New South Wales, and several smaller intrusions, such as those near Bodalla, Moruya, Coondella and Nelligen, which may be regarded as apophyses of the main batholith.

Although the writer has not yet had the opportunity of carrying out a chemical investigation of the main batholith, its field and petrological examination indicates that differentiation took place in a manner similar to that which occurred at Moruya. It has been shown (1928) that here the igneous rocks form a complete and typical subalkaline complex, as indicated by the accompanying variation-diagram (Text-figure 2).

The differentiation was of a serial character, and probably took place by means of fractional crystallization and the sinking of crystals in the manner postulated by N. L. Bowen (1915, 1919). It was considered (1928, p. 186) that this process took place in an intercrustal magma-chamber and that the apparent intrusive relationships between the chief plutonic types were due to successive injections of magma of increasing acidity and increasing alkalinity from the hypothetical magma-reservoir. There is no clear evidence to show that such has been the case, and the increasing number of described occurrences of a similar nature in which magmatic differentiation has occurred practically in place, suggests that a similar process may have taken place in the Moruya magma, and that slight earth-movements during its consolidation are responsible for the apparent intrusive relationships.



Text-figure 2.—Variation diagram for the igneous complex of the Moruya district.

Magmatic differentiation may have proceeded as well in the large apophyses as in the main batholith, without any intermediate magma reservoir as such, and with the production of similar rock-series on different scales of magnitude. Possibly the greater volume of magma in the main batholith and the resultant slower cooling is responsible for the formation of more coarsely-crystalline rocks than the mineralogically equivalent types in the smaller intrusions. The formation of complementary dyke-rocks, aplites and dolerites, took place during the later stages of consolidation of the magma. Associated with these and the final stages are metalliferous deposits, gold and ores of bismuth, molybdenum, arsenic with traces of silver, lead, zinc and tin.

The flows of the Illawarra District give evidence of slight progressive magmatic differentiation during late Kamilaroi time, but this variation is only of the order which obtains within one of the larger flows, such as that of Bumbo (G. W. Card, 1915, p. 285). Late-magmatic or deuteric processes have operated to a considerable extent in some of these flows, as shown by the work of W. R. Browne and H. P. White (1928).

Somewhat similar conditions prevail among the Milton monzonitic rocks (I. A. Brown, 1925*b*). There are only slight variations in the chemical composition of different phases of the main intrusion, although there are differences in texture and mineralogical composition. The occurrence of cognate xenoliths and aplitic and pegmatitic segregation veins indicates greater magmatic differentiation than appears to have taken place among the volcanic equivalents of the Illawarra. Possibly this is due to the form of the intrusion and the depth of cover at the time of injection, which permitted slower cooling and crystallization. During the final stages of consolidation, albitization and associated processes operated in this mass also, particularly in the more coarsely crystalline portions.

The igneous complex at Mount Dromedary gives evidence of much more complicated differentiation than has taken place in the other monzonitic occurrences of the South Coast (I. A. Brown, 1930*b*, pp. 688–691). The intrusion is in the form of a laccolith which probably had a fairly thick sedimentary cover at the time of injection. The variety and arrangement of the rock-types developed in this occurrence indicate that the relatively great thickness (3,000 feet) and slow cooling of the laccolith afforded opportunity for the differentiation of the magma *in situ*, by means of fractional crystallization and the sinking of crystals under gravity, as postulated by Bowen (1915, 1919), Harker (1909, p. 317; 1913) and others.

As a result, the main monzonitic series, including the banatite, monzonites, shonkinite and pyroxenite, was produced. Probably earth-movements during the consolidation of the magma were responsible for the partial injection of the banatite into the monzonite, and also indirectly for the development of an associated series of nepheline-bearing rocks, nepheline-shonkinite and nepheline-monzonites, as a result of filter-press action. The origin of the associated garnet-bearing series is obscure. The accompanying variation-diagram (Text-figure 3) illustrating the chemical composition of the occurrence indicates that the garnet-bearing rocks are not directly related to the monzonitic series, although field and mineralogical evidence is in favour of some degree of consanguinity.

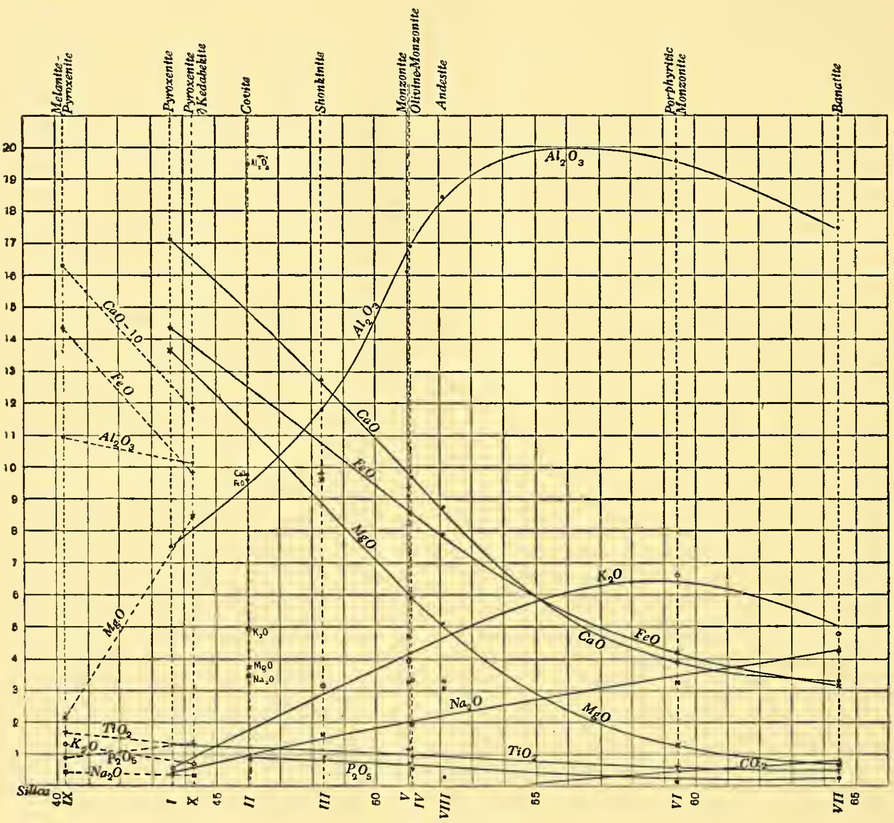
The possibility that the garnet-bearing rocks are due to the incorporation of limestone by the monzonitic magma has been considered previously by the writer (1930*b*, pp. 690, 691), and no further information is available on the subject.

The later stages of consolidation are represented by aplitic and lamprophyric dykes and veins in the main intrusion. The formation of volcanic necks or plugs, containing inclusions of the plutonic types, marks the final phase of igneous activity in this locality.

The igneous rocks which have been referred to the Tertiary period show great diversity, which is characteristic of alkaline rocks all over the world.

Magmatic differentiation evidently took place in an intercrustal reservoir and successive periods of injection are indicated by numbers of small intrusions, which are more or less homogeneous in composition and which may be grouped into series possessing certain distinctive chemical characters. Thus the early intrusions of lamprophyres are basic, distinguished by relatively high alumina and high alkalis; the monchiquites are still more basic with lower alumina, but with higher magnesia, lime and water. Similar variations occur among the nepheline-syenites and dolerites which were probably injected at a somewhat later period.

The basalts are probably the latest expressions of igneous activity in the area. These are not normal basalts, but show decidedly alkaline affinities, indicated mineralogically by the presence of analcite and (normative) nepheline in almost every case, and shown chemically by the relatively high amounts of alkalis and titania.



Text-figure 3.

Differentiation *in situ* occurred only in the larger intrusions, such as those of the Good Dog Mountains and Bowral.

(*b*). The possibility that magmatic differentiation has operated over a large region throughout the whole of geological time, is suggested by the progressive change in alkalinity and basicity of the injected magma in the area under consideration. Tectonic disturbances at various periods have provided a means for the injection of magma into the upper layers of the earth's crust, and at times may have assisted the process of magmatic differentiation by filter-press action, the squeezing out of the liquid portion from a partially solid mass. Magmatic differentiation has been intensified shortly before and sometimes after diastrophic periods when igneous activity has occurred.

Thus during the middle Palaeozoic the South Coast was essentially a subalkaline province, but complementary differentiates, which formed rhyolites and basalts, were extravasated before the injection of the granodioritic magma, and probably differentiation of the latter took place almost *in situ* in the batholiths.

In Kamílaroi time the average composition of the magma was monzonitic, more alkaline and more basic than that of earlier time, and the magma was not highly differentiated before injection to its final position, but under suitable conditions, as at Mt. Dromedary, magmatic differentiation was able to proceed almost to its possible limit, and a great variety of monzonitic and associated alkaline types were produced.

In Tertiary time the average composition of the mother-magma was that of an alkaline basalt, the actual weight percentage of alkalis being less than those of the average monzonitic or subalkaline series, but relatively high for a basic magma. Here again, intensified magmatic differentiation prior to extravasation was the general rule, for individual intrusions are of fairly uniform composition and only under particularly favourable conditions did differentiation occur in the final position of consolidation.

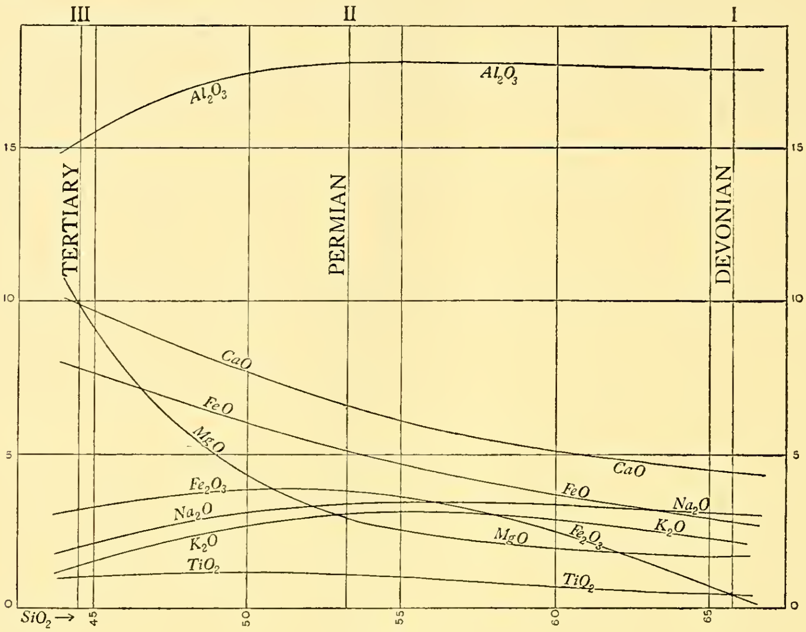
The change in average composition of the magma injected during these three epochs is illustrated in the accompanying variation-diagram (Text-figure 4), based on the analyses of (i) the Moruya granodiorite (Devonian), (ii) the Milton monzonite (Kamílaroi) and (iii) the Robertson flow of alkaline basalt (Tertiary), which are regarded as the most representative available analyses.

The resultant curves for the various oxides give a diagram, which is typical of a subalkaline igneous series, and which may be compared directly with the variation-diagram for the Moruya complex (Text-figure 2) for a similar range of the silica percentage. It is considered that this detailed similarity indicates that the rocks (or magmas they represent) are genetically related, and that therefore the subalkaline, monzonitic and alkaline series of the South Coast are consanguineous.

If this conclusion be justified, then magmatic differentiation has operated on (potential) magma over a long period of time, at least from the Devonian period to the late Tertiary. It is not intended to imply that this magma was in a fluid state throughout the whole of geological time, but that diastrophic periods have afforded opportunity for the liquefaction and injection of portions of the magma into the upper layers of the earth's crust, where subsequent magmatic differentiation, influenced by local factors, has produced various series of related rocks.

The Tertiary alkaline rocks of the South Coast are regarded therefore as normal products of differentiation: the writer is not aware of any evidence that their occurrence is influenced by association with limestone, as implied by R. A. Daly (1910, 1914, Appendix D, p. 523), for the intruded Kamílaroi and Triassic sediments contain no massive limestones, and the underlying Upper Devonian and older Palaeozoic series are quite devoid of limestone in this region.

It is considered by the writer that further evidence of the production of the chief occurrences of alkaline rocks as a result of normal magmatic differentiation over a long period of time is afforded by the conclusion of H. I. Jensen (1908, p. 585) that "Almost all the great alkaline eruptions of all parts of the earth took place in the Eocene period" and that these occurred "along the borders of Mesozoic epi-continental basins or transgressions which have been broadly uplifted without much folding".



Text-figure 4.

Monzonitic series in other parts of the world are frequently younger than the subalkaline rocks with which they are associated: in most cases where their age can be proved it is found to be late Palaeozoic or Mesozoic, that is, in general, intermediate in age between the subalkaline and alkaline series of any particular region.

It therefore seems possible that the origin and relationships of the igneous rocks of the South Coast of New South Wales may be typical and representative of conditions in other parts of the world, and that in any particular region, which contains a record of geological history throughout several eras, magmatic differentiation has operated on a grand scale throughout geological time. The earlier intrusions are subalkaline in character and the later ones are progressively more basic and relatively more alkaline: their manifestation at the surface of the earth has been brought about by tectonic disturbances, which may sometimes have had an influence on the chemical composition of the injected magma. The subsequent differentiation of a particular mass of injected magma has been dependent on local conditions, and various factors have operated to produce a great variety of igneous rocks.

6. Summary and Conclusions.

The South Coast of New South Wales may be regarded as a section across the margin of a continental mass, which has been growing by the repeated deposition of sediments along its borders and their subsequent elevation and compression to form portion of the land-mass.

The paper gives an account of the distribution, lithological characters, mutual relationships and tectonic structures of the sedimentary rocks, whose ages range from Cambrian (?) to Post-Tertiary, and summarizes the field-occurrence and petrological and chemical characters of the associated igneous rocks, which belong to three principal periods of igneous activity. These are referred to the Devonian, Kamilaroi and Tertiary periods, which are represented by rocks of subalkaline, monzonitic and alkaline facies, respectively.

A consideration of the tectonic history shows that during early Palaeozoic time the present south coastal area was portion of a "borderland", which was separated from the continental massif by the Nullagine geosyncline, an inheritance from Pre-Cambrian time. The early Palaeozoic history of south-eastern Australia was essentially that of the infilling of this geosyncline until the close of the Middle Devonian, when, during a period of diastrophism, the present south coastal district became portion of the continental mass. This remained a positive area during the Carboniferous. The area to the north and east gradually subsided and developed into the geosyncline of Kamilaroi and Triassic times, in which the axis of greatest sedimentation moved slowly to the north and east. Cainozoic earth-movements were chiefly epeirogenic.

There is a close relationship between the history of igneous activity and the tectonic history of the region. Terrestrial flows of rhyolite and basalt heralded subsidence and the deposition of Upper Devonian sediments; the subsequent folding of these beds was accompanied by the intrusion of granodioritic (subalkaline) batholiths, whose elongation is parallel to the axes of folding of the Upper Devonian sediments. Vertical adjustments about the borders of the Kamilaroi geosyncline were associated with intrusions and extrusions of monzonitic magma during Upper Marine time, and epeirogenic movements during the Tertiary period were accompanied by the extravasation of basic, alkaline magma.

Thus, viewed broadly, the relations of the subalkaline and alkaline rocks of the region under consideration to the accompanying orogenic and epeirogenic earth-movements are essentially in accordance with Harker's generalization on the subject.

The progressive change in the basicity and alkalinity of the injected magma in the region under consideration suggests an ultimately comagmatic origin for all the igneous rocks, which is confirmed to some extent by the form of the variation-diagram, based on representative chemical analyses of Devonian (subalkaline); Kamilaroi (monzonitic) and Tertiary (alkaline) rocks.

It is concluded that probably magmatic differentiation has operated on potential magma for a long period of time, extending at least from the Devonian to the Tertiary periods on the South Coast. Diastrophic movements have afforded opportunity for the liquefaction and injection of portions of the magma into the upper layers of the earth's crust, and sometimes may have assisted the process of differentiation by filter-press action. Magmatic differentiation was intensified sometimes before, and usually after, injection of the magma into its final position, where various local factors have influenced the subsequent course of differentiation and the production of the closely related rock-series which are described in the paper.

The alkaline rocks are regarded therefore as normal products of magmatic differentiation, and there appears to be no evidence that they are due to assimilation of limestone in this region.

A brief general survey of the occurrence of subalkaline and alkaline rocks in other parts of the world suggests that the origin and relationships of the igneous rocks of the South Coast may be typical and representative of conditions elsewhere.

The paper is accompanied by variation-diagrams illustrating local and regional magmatic differentiation, and by a geological sketch-map of the South Coast of New South Wales.

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EXPLANATION OF PLATE XXVIII.

Geological Sketch-map of the South Coast of New South Wales.